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Ammonia observations of the nearby molecular cloud MBM 12

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ABSTRACT

We present NH_3(1,1) and (2,2) observations of MBM 12, the closest known molecular cloud (65-pc distance), aimed at finding evidence for on-going star formation processes. No local temperature (with a T_{rot} upper limit of 12 K) or linewidth enhancement is found, which suggests that the area of the cloud that we have mapped (∼15-arcmin size) is not currently forming stars. Therefore this nearby 'starless' molecular gas region is an ideal laboratory to study the physical conditions preceding new star formation.

A radio continuum source has been found in Very Large Array archive data, close to but outside the NH_3 emission. This source is likely to be a background object.

Key words: stars: formation – ISM: clouds – ISM: individual: MBM 12 – ISM: molecules – radio lines: ISM.

1 INTRODUCTION

MBM 12 (Magnani, Blitz & Mundy 1985) is the closest known molecular cloud. Its distance has been estimated to be ∼65 pc (Hobbs, Blitz & Magnani 1986).This means that the distance to MBM 12 is less than half of that to the closest star formation complexes (e.g. 140 pc to Taurus). Therefore determining the presence of star-forming processes in MBM 12 would allow us to get deep into the smallest possible physical scales of these processes. For instance, for young low-mass stars a critical scale is ∼100 au, which is the estimated size of protoplanetary discs, and the distance at which jets are being collimated (Rodríguez 1989). A size of 100 au at 65 pc will extend ∼1.5 arcsec, which is a resolution attainable at present, for instance by millimetre interferometers already operating. However, similar studies in more distant star-forming regions would require subarcsecond resolution, for which we will have to wait until the next generation of interferometers is available.

Although no ongoing star formation has been detected so far within this high-latitude cloud, the presence of T Tauri stars (Pound 1996) outside but close to the bulk of the CO emission (Pound, Bania & Wilson 1990; Zimmerman & Ungerechts 1990; Moriarty-Schieven, Andersson & Wanner 1997) suggests that, at least in the near past, this cloud has been a star-forming site. However, it might be possible that these T Tauri stars are runaway objects from other star-forming regions. The detection of embedded young stellar objects would then be the only way to confirm whether MBM 12 is actually a star-forming region.

Reach et al. (1995) have determined the presence of dense gas ($\gtrsim 10^4$ cm^{-3}, traced by CS emission) in some areas of MBM 12, forming clumps in near-virial equilibrium (i.e. dynamically bound, not just density fluctuations in a turbulent medium). Therefore these are possible pre-stellar cores (Ward-Thompson et al. 1994) which merit further study.

In this paper, we present single-dish NH_3 observations aimed at searching for evidence of on-going star formation in MBM 12. NH_3 observations can be used to identify the presence of current star formation processes. The ratio between different NH_3 transitions gives us temperature information (Ho & Townes 1983). Local heating effects traced by ammonia have been successfully used to locate young stellar objects (e.g. Gómez et al. 1994; Girart et al. 1997). Moreover, local peaks of linewidth could indicate local turbulence enhancements, which are also very likely to be associated with star-forming processes.

We have also used radio continuum observations from the NRAO Very Large Array (VLA) archive, to look for possible embedded young stellar objects.

2 OBSERVATIONS

Observations of the NH_3(1,1) and (2,2) inversion lines (rest frequencies $\nu_{11} = 23.6944955$ GHz and $\nu_{22} = 23.7226333$ GHz) were taken with the 37-m antenna at Haystack Observatory on

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1998 March 17–24, and 1998 May 13–15. The beamsize of the telescope at this frequency is ~1.44 arcmin (which corresponds to ~0.03 pc on MBM 12). We used a dual-maser, cryogenically cooled receiver, which was tuned at a frequency mid-way between those of the observed lines, and with $V_{LSR} = -5.0\,\mathrm{km\,s^{-1}}$. The autocorrelation spectrometer was configured to measure a bandwidth of 53.3 MHz with 1024 lags, which gave a spectral resolution of 62.85 kHz ($0.8\,\mathrm{km\,s^{-1}}$). This system setup allowed us to obtain spectra that included both NH_3 lines. Two circular polarizations were also obtained simultaneously. The rms pointing error was estimated to be ~11 arcsec, with observations of Saturn. The reference position of our NH_3 maps is $\alpha(1950) = 02^h53^m08\overset{s}{.}9$, $\delta(1950) = +19°14'15''$. The spectra have all been corrected for antenna gain and atmospheric attenuation. Typical system temperatures are ~100 K. The final spectra have been smoothed up to a velocity resolution of $1\,\mathrm{km\,s^{-1}}$, yielding an rms noise level of ~0.03 K. Data reduction was performed with the program CLASS of IRAM and Observatoire de Grenoble.

We also used archive VLA data towards this region. These data correspond to B-array, 3.6-cm continuum observations, originally taken by D. Helfand and J. Halpern on 1990 August 2, to search for a radio counterpart of the X-ray pulsar H0253+193 (see Patterson & Halpern 1990; Zuckerman et al. 1992). An effective bandwidth of 100 MHz and two circular polarizations were observed. The phase centre was located at $\alpha(1950) = 02^h53^m20\overset{s}{.}5$, $\delta(1950) = +19°14'38''$. The source 1328+307 was used as the primary flux calibrator, with an assumed flux density of 5.19 Jy. The phase calibrator was 0235+164, for which a flux density of 3.44 ± 0.06 was derived. Calibration and further image processing were performed with the program AIPS of NRAO. The resulting synthesized beam was $0.84 \times 0.72\,\mathrm{arcsec^2}$, and the rms noise level $1.0 \times 10^{-2}\,\mathrm{mJy\,beam^{-1}}$.

3 RESULTS

Fig. 1 shows the emission of the $NH_3(1,1)$ line detected at different velocities. Fig. 2 shows the integrated intensity map. Several clumps of ammonia emission are evident in this latter figure, the most intense one centred around position offset (1.44 arcmin, 0.00 arcmin). The observed clumps tend to align, forming two clear filamentary structures, one extending south to north between position offsets (1.44 arcmin, −2.88 arcmin) and (1.44 arcmin, 4.32 arcmin), and the other one from south-east to north-west between (−2.88 arcmin, 1.44 arcmin) and (− 7.20 arcmin, 4.32 arcmin). The morphology seen with our NH_3 maps is similar to that in CO (Pound et al. 1990; Zimmerman & Ungerechts 1990; Moriarty-Schieven et al. 1997), and especially to the CS map (Reach et al. 1995). Fig. 3 shows an averaged spectrum within a box of $3 \times 3\,\mathrm{arcmin^2}$ around (1.44 arcmin, 0.00 arcmin), which includes the NH_3 emission from the most intense clump. Apart from the central, main hyperfine component, the satellite lines of $NH_3(1,1)$ are also evident. No $NH_3(2,2)$ line emission was detected in our spectra. This emission is not present even in the average within the $3 \times 3\,\mathrm{arcmin^2}$ box around (1.44 arcmin, 0.00 arcmin), with an upper limit[1] of 0.020 K.

No radio continuum emission is detected within the bounds of the ammonia emission, with an upper limit to the flux density of 2.3×10^{-2} mJy. Only an unresolved source is present within the primary beam of the VLA, with a flux density of 0.114 ± 0.026 mJy, at position $\alpha(1950) = 02^h53^m26\overset{s}{.}38$, $\delta(1950) = +19°14'44\overset{''}{.}4$ (we name this object VLA B0253+192). Note that the phase centre of the VLA observations is located at position offset (2.74 arcmin, 0.38 arcmin) in our NH_3 maps, and the primary beam at 3.6 cm is 5.4 arcmin (FWHM). Therefore this primary beam includes the whole central clump. The position of VLA B0253+192 is indicated in Figs 1 and 2.

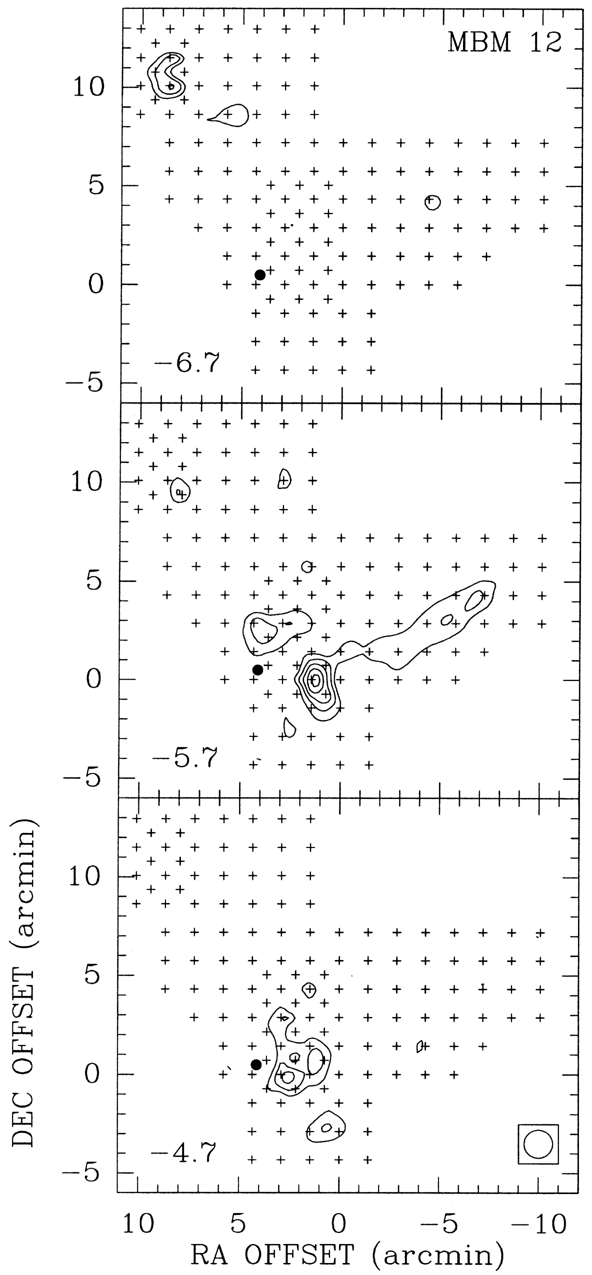

Figure 1. Contour maps of $NH_3(1,1)$ intensity, at different velocities. The LSR velocity (in $\mathrm{km\,s^{-1}}$) is indicated at the bottom left corner of each panel. The lowest contour is 0.09 K and the increment step is 0.03 K (1σ). The filled circle indicates the position of the radio source VLA B0253+192. Crosses indicate the observed points. The beamsize is indicated as a circle at the bottom right corner.

[1] Upper limits and errors are given in this paper for a 99 per cent confidence level.

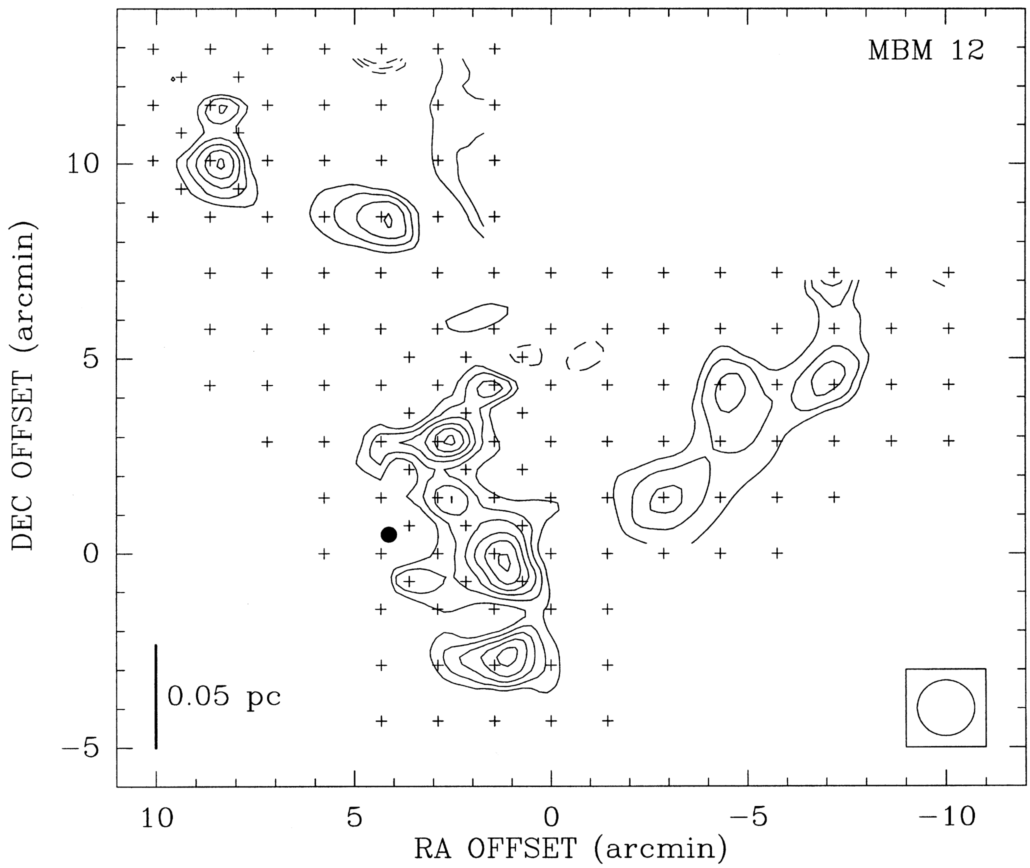

Figure 2. Contour map of the integrated emission of the $NH_3(1,1)$ main hyperfine component. The integration range was between −8.1 and −2.9 km s^{-1}. The lowest contour is 0.15 K km s^{-1}, and the increment step is 0.05 K km s^{-1}. Symbols have the same meaning as in Fig. 1.

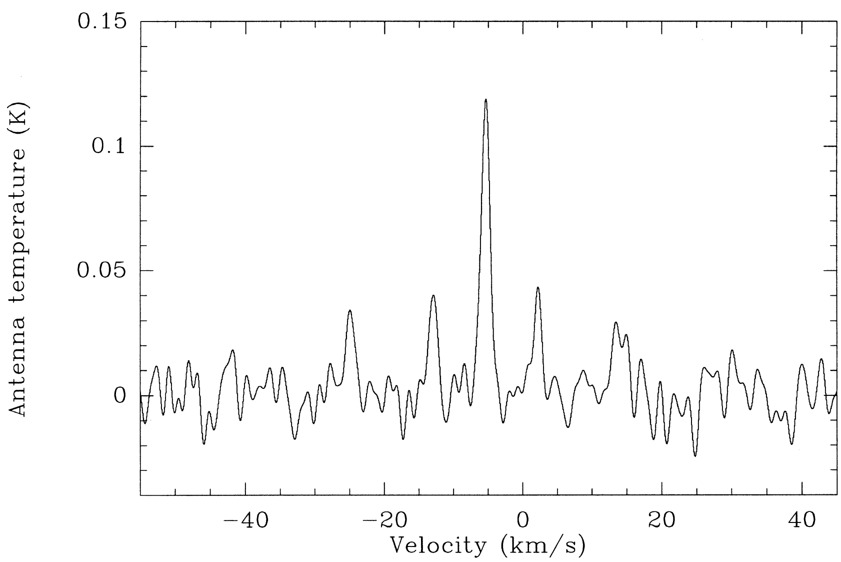

Figure 3. Averaged spectrum of the $NH_3(1,1)$ line, within a box of 3 × 3 arcmin^2 around position offset (1.44 arcmin, 0.00 arcmin).

4 DISCUSSION AND CONCLUSIONS

The main goal of our NH_3 observations was to identify the presence of on-going star formation processes, by measuring local temperature and turbulence enhancements.

In our data, the lack of $NH_3(2,2)$ emission indicates a low temperature throughout the mapped area. In particular, from the averaged data for the most intense clump, around (1.44 arcmin, 0.00 arcmin) (see Fig. 3), and using the values for the main and inner satellite components $T_A(1,1;\mathrm{m}) = 0.117 \pm 0.022$ K, $T_A(1,1;\mathrm{is}) = 0.041 \pm 0.016$ K, $T_A(2,2;\mathrm{m}) < 0.020$ K, we derive an optical depth of $\tau(1,1;\mathrm{m}) = 0.69$ and an upper limit to the rotational temperature of ~12 K. This temperature is similar to those found in other high-latitude clouds, including MBM 7

(Turner 1995), which is close to MBM 12. This rotational temperature is also expected to be close to the value of the local kinetic temperature (Turner 1995). No local linewidth enhancement is seen in our data. Typical linewidths seem to be unresolved with our $1\,\mathrm{km\,s^{-1}}$ velocity resolution.

From these results we conclude that no indication of current star formation is evident in our NH_3 data. This suggests that T Tauri stars seen close to MBM 12 (Pound et al. 1990) were formed in the near-past, but star-forming processes are no longer going on, at least in the area that we mapped. Alternatively, those T Tauri stars may be runaway objects from nearby star formation sites.

However, Reach et al. (1995) estimated that MBM 12 is a potential star-forming cloud, given the similar mass derived from the CS integrated intensity and the virial mass. In our data, for the main clump around (1.44 arcmin, 0.00 arcmin), and assuming a $T_\mathrm{k} = T_\mathrm{rot} = 12\,\mathrm{K}$, we estimate a mass of $0.12(X_{\mathrm{NH_3}}/10^{-8})^{-1}\,\mathrm{M_\odot}$, where $X_{\mathrm{NH_3}}$ is the molecular abundance of NH_3 with respect to H_2. The total mass for the clumps mapped in our data is $\sim 0.65(X_{\mathrm{NH_3}}/10^{-8})^{-1}\,\mathrm{M_\odot}$. These values are consistent with those obtained by Reach et al. (1995). Although we see no sign of current star formation processes, the presence of self-gravitating clumps suggests the possibility of these processes occurring in the future. Therefore, given its proximity to the Sun, this region is an ideal laboratory to study pre-collapsing physical conditions, preceding new star formation (e.g. Ward-Thompson et al. 1994).

On the other hand, the radio continuum source that lies within our sampled area does not seem to be a young stellar object associated with MBM 12, since it is outside the bounds of the NH_3 emission. Association with NH_3 emission is a known characteristic of young stellar objects (Anglada et al. 1989). The source VLA B0253+192 is likely to be an extragalactic object.

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